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Experimental investigation on properties of concrete using manufactured sand granite powder and bottom ash as partial replacement of fine aggregate

[1]Alluri Anil Kumar ,[2]Gollapelli Srikanth,[3] Mohammad Majeed,[4]Syed Adnanuddin ,[5] Mohammed Samiuddin,[6] Mohammad Saad

[1,2] Assistant Professor, Department of Civil Engineering, Lords Institute of Engineering & Technology, Himayat Sagar, Hyderabad,Telangana, India –500091

[3,4,5,6] PG Student, Department of Civil Engineering, Lords Institute of Engineering & Technology, Himayat Sagar, Hyderabad, Telangana India.–500091

[1]anilkumar@lords.ac.in,[2]Srikanth.g@lords.ac.in,[3]md.majeed026@gmail.com,[4]syedadnan555555@gmail.com,[5]mohammedsamiuddin787@gmail.com,[6]mohammedsaad5741@gmail.com

Abstract

This experimental study investigates the influence of granite powder and bottom ash as partial replacements in manufactured sand (M-sand) on the properties of concrete. Fine aggregates play a crucial role in determining the strength and durability of concrete. However, natural sand resources are depleting, prompting the need for sustainable alternatives. Manufactured sand, a byproduct of crushed stone, offers a viable substitute. In this study, granite powder and bottom ash were used to partially replace M-sand in varying proportions (10%, 20%, 30%, 40%, and 50%) to analyze their effects on fresh and hardened properties of concrete. Standard M30 grade concrete was used to maintain consistency across all mixes. Tests such as workability, compressive strength, split tensile strength, and flexural strength were conducted at 7 and 28 days of curing. The results indicate that moderate replacement levels improved certain strength parameters, while higher replacements led to marginal reductions in strength. This study promotes the utilization of industrial and construction waste in concrete, enhancing sustainability and minimizing environmental impact.

Keywords: Manufactured Sand (M-Sand), Granite Powder, Bottom Ash, Partial Replacement of Fine Aggregate, Compressive Strength, Split Tensile Strength, Flexural Strength, Sustainable Concrete, Industrial Waste Utilization, Concrete Properties.

I. Introduction

Concrete is the most widely used construction material, and fine aggregates significantly influence its strength and durability. The increasing depletion of natural river sand due to extensive construction activities has created a need for sustainable alternative materials. Manufactured sand (M-sand) has emerged as a suitable replacement for natural sand because of its consistent quality and availability.

Granite powder and bottom ash are industrial by-products generated from granite processing industries and thermal power plants, respectively. The disposal of these waste materials poses environmental challenges. Their utilization in concrete can reduce waste accumulation, conserve natural resources, and promote sustainable construction practices.

This study investigates the effect of partially replacing M-sand with granite powder and bottom ash at replacement levels of 10%, 20%, 30%, 40%, and 50% in M30 grade concrete. The fresh and hardened properties of concrete were evaluated through workability, compressive strength, split tensile strength, and flexural strength tests at 7 and 28 days of curing.

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The primary objective of this research is to assess the feasibility of using granite powder and bottom ash as fine aggregate replacements and to determine the optimum replacement level that enhances concrete performance while improving sustainability.

1.1 Objectives

- To investigate the feasibility of using granite powder and bottom ash as partial replacements of manufactured sand (M-sand) in concrete.
- To replace M-sand with granite powder and bottom ash at 10%, 20%, 30%, 40%, and 50% replacement levels.
- To evaluate the workability, compressive strength, split tensile strength, and flexural strength of concrete.
- To compare the performance of modified concrete mixes with conventional M-sand concrete.
- To determine the optimum replacement percentage for enhanced strength and sustainable concrete production.

1.2 Scope of the Study

- Preparation of M30 grade concrete using M-sand as fine aggregate.
- Partial replacement of M-sand with granite powder and bottom ash at different proportions.
- Investigation of fresh and hardened properties of concrete.
- Assessment of compressive strength, split tensile strength, and flexural strength at 7 and 28 days of curing.
- Identification of the optimum replacement level for improved performance and sustainability.

1.3 Need of the Project

- To address the depletion of natural river sand resources.
- To utilize industrial and construction waste materials effectively.
- To reduce environmental problems associated with the disposal of granite powder and bottom ash.
- To promote sustainable and eco-friendly concrete production.
- To develop economical concrete with improved engineering properties.

1.4 Significance of the Study

- Encourages the utilization of industrial by-products in concrete.
- Reduces dependence on natural fine aggregate resources.
- Promotes sustainable construction practices and waste management.
- Minimizes environmental pollution caused by granite powder and bottom ash disposal.
- Provides an alternative approach for producing durable and eco-friendly concrete.

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II. Literature Review

- Several researchers have investigated the use of alternative fine aggregate materials and industrial by-products to improve the performance and sustainability of concrete.
- Studies on manufactured sand (M-sand) have shown that it can effectively replace natural river sand while maintaining satisfactory strength and durability characteristics. Due to its controlled grading and availability, M-sand has become a widely accepted alternative fine aggregate in concrete production.
- Research on granite powder indicates that it can be utilized as a partial replacement for fine aggregate because of its fine particle size and filler effect. The incorporation of granite powder improves particle packing density and contributes to strength development at suitable replacement levels.
- Bottom ash, a by-product of thermal power plants, has also been extensively studied as a fine aggregate substitute. Researchers have reported that bottom ash can enhance workability and contribute to sustainable concrete production. However, excessive replacement levels may lead to reductions in strength due to its porous nature.
- Previous studies involving the combined use of granite powder and bottom ash have demonstrated promising results in improving concrete properties while reducing environmental impacts. The utilization of these waste materials helps conserve natural resources and minimizes landfill disposal requirements.
- Based on the findings of earlier research, the present study investigates the combined effect of granite powder and bottom ash as partial replacements of M-sand at 10%, 20%, 30%, 40%, and 50% replacement levels in M30 grade concrete and evaluates their influence on workability, compressive strength, split tensile strength, and flexural strength.

III. Proposed Research Methodology

The methodology presents the step-by-step procedure adopted for the experimental investigation and explains the materials, mix preparation, testing procedures, and analysis of results.

Figure 3.1: Flow Chart of Methodology

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- M30 grade concrete was prepared using manufactured sand (M-sand) as the fine aggregate. Granite powder and bottom ash were used as partial replacements of M-sand at replacement levels of 10%, 20%, 30%, 40%, and 50%. A control mix containing 100% M-sand was also prepared for comparison.
- Concrete specimens were cast and cured under standard conditions. Workability tests were conducted on fresh concrete, while compressive strength, split tensile strength, and flexural strength tests were performed on hardened concrete specimens at 7 and 28 days of curing.
- The experimental results were analyzed to evaluate the influence of granite powder and bottom ash on concrete properties and to determine the optimum replacement percentage for achieving enhanced strength and sustainable concrete production.

4.1 Mix Design

The mix design for M30 grade concrete was carried out in accordance with the guidelines of IS 10262:2019. Manufactured Sand (M-Sand) was used as the fine aggregate, while Granite Powder (GP) and Bottom Ash (BA) were utilized as partial replacements of M-Sand at various replacement levels. A superplasticizer was incorporated to enhance the workability of the concrete mix. The concrete was designed to achieve the target mean strength requirements of M30 grade concrete.

4.2 Mix Proportion

Granite Powder and Bottom Ash were used as partial replacements of M-Sand in different percentages to study their effect on the workability and strength characteristics of concrete. Concrete specimens were prepared using the selected mix proportions and tested for compressive strength, split tensile strength, and flexural strength. The control mix proportion adopted for M30 grade concrete is presented in Table 4.1.

Table 4.2.1 Mix Proportion for M30 Grade Concrete

Material	Quantity (kg/m³)
Cement	356
Water	149
Fine Aggregate (M-Sand + GP/BA)	779
Coarse Aggregate (20 mm)	1191
Superplasticizer	3.2

The above mix proportion was taken as the control mix, and Granite Powder and Bottom Ash were introduced as partial replacements of M-Sand in varying percentages to evaluate their influence on the mechanical properties of concrete. The specimens were cast, cured for 7 and 28 days, and tested to compare their performance with that of conventional concrete.

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4.3 Tests on Hardened Concrete

4.3.1 Compressive Strength Test

- The compressive strength test was conducted in accordance with the guidelines of IS 516:2018 on concrete cube specimens of size 150 mm × 150 mm × 150 mm. The specimens were cast using M30 grade concrete containing Manufactured Sand (M-Sand), Granite Powder (GP), and Bottom Ash (BA) as fine aggregate materials. After casting, the specimens were cured in water for the required curing periods.
- The compressive strength was determined at the ages of 7 and 28 days. Before testing, the specimens were removed from the curing tank, cleaned, and placed centrally in a Compression Testing Machine (CTM). The load was applied gradually and continuously until failure occurred. The maximum load carried by each specimen was recorded. The compressive strength was calculated by dividing the ultimate load by the loaded area of the cube specimen.
- The average compressive strength values obtained from three specimens for each mix were considered for analysis and comparison. The test was carried out to evaluate the influence of Granite Powder and Bottom Ash as partial replacements of M-Sand on the compressive strength characteristics of concrete.

Figure 4.1 Compressive Strength Test

Table 4.3.1 Compressive Strength of Concrete Specimens for 7, 14 and 28 Days

S. No	Mix ID	Replacement Material	% Replacement	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	CM	—	0%	26.5	32.4	38.2
2	GP10	Granite Powder	10%	27.4	33.8	39.8
3	GP20	Granite Powder	20%	28.1	34.5	40.2
4	GP30	Granite Powder	30%	27.8	34.0	39.6
5	GP40	Granite Powder	40%	25.2	31.2	36.4
6	GP50	Granite Powder	50%	23.9	29.4	34.7
7	BA10	Bottom Ash	10%	26.9	32.9	38.7
8	BA20	Bottom Ash	20%	27.2	33.5	39.5
9	BA30	Bottom Ash	30%	26.5	32.6	38.3
10	BA40	Bottom Ash	40%	25.1	30.8	36.1
11	BA50	Bottom Ash	50%	23.8	29.1	34.0

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Calculation:

Size of Cube = 150 mm × 150 mm × 150 mm

Area of Cube = Length × Breadth

= 150 × 150

= 22,500 mm²

Failure Load of Cube at 28 Days (GP20 Mix) = 905 kN

Compressive Strength = Failure Load / Loaded Area

= (905 × 1000) / 22,500

= 40.22 N/mm²

≈ 40.2 MPa

Discussion:

The compressive strength increased with the replacement of M-Sand by Granite Powder and Bottom Ash up to 20% replacement. The maximum compressive strength of 40.2 MPa was achieved for the GP20 mix at 28 days. Further increase in replacement percentage resulted in a reduction in strength. Hence, 20% Granite Powder (GP20) was found to be the optimum replacement level for achieving maximum compressive strength.

4.3.2 Split Tensile Strength Test

The split tensile strength test was conducted in accordance with IS 516 on cylindrical concrete specimens of size 150 mm diameter and 300 mm height. The specimens were tested at 7, 14, and 28 days of curing. The load was applied gradually along the diameter of the cylinder until failure occurred, and the split tensile strength was determined.

Figure 4.2 Split Tensile Strength Test

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Table 4.3.2 Split Tensile Strength of Concrete Specimens for 7, 14 and 28 Days

S. No	Mix ID	Replacement Material	% Replacement	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	CM	—	0%	2.65	3.18	3.82
2	GP10	Granite Powder	10%	2.78	3.32	4.05
3	GP20	Granite Powder	20%	2.86	3.45	4.18
4	GP30	Granite Powder	30%	2.80	3.38	4.10
5	GP40	Granite Powder	40%	2.52	3.02	3.68
6	GP50	Granite Powder	50%	2.34	2.85	3.42
7	BA10	Bottom Ash	10%	2.70	3.24	3.90
8	BA20	Bottom Ash	20%	2.76	3.30	4.00
9	BA30	Bottom Ash	30%	2.66	3.20	3.84
10	BA40	Bottom Ash	40%	2.48	2.98	3.60
11	BA50	Bottom Ash	50%	2.30	2.80	3.35

Calculation:

Diameter of Cylinder (**D**) = **150 mm**

Length of Cylinder (**L**) = **300 mm**

Split Tensile Strength,

$ft = 2P / \pi DL$

Where,

P = Ultimate Load (N)

D = Diameter of Cylinder (mm)

L = Length of Cylinder (mm)

From the test results, the maximum split tensile strength of 4.18 MPa at 28 days was obtained for Mix GP20 containing 20% Granite Powder replacement, indicating that the addition of 20% Granite Powder provided the optimum improvement in the tensile strength of concrete among all the mixes considered.

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4.3.3 Flexural Strength Test

The flexural strength test was conducted in accordance with IS 516 on beam specimens of size 150 mm × 150 mm × 700 mm. The specimens were tested under two-point loading at 7, 14, and 28 days. The maximum load at failure was recorded, and the flexural strength was calculated.

Figure 4.3 Flexural Strength Test

Table 4.3.3 Flexural Strength of Concrete Specimens for 7, 14 and 28 Days

S. No	Mix ID	Replacement Material	% Replacement	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	CM	—	0%	3.45	4.18	5.12
2	GP10	Granite Powder	10%	3.60	4.35	5.38
3	GP20	Granite Powder	20%	3.72	4.52	5.56
4	GP30	Granite Powder	30%	3.65	4.45	5.42
5	GP40	Granite Powder	40%	3.30	4.02	4.92
6	GP50	Granite Powder	50%	3.08	3.78	4.58
7	BA10	Bottom Ash	10%	3.50	4.24	5.20
8	BA20	Bottom Ash	20%	3.58	4.32	5.32
9	BA30	Bottom Ash	30%	3.46	4.20	5.10
10	BA40	Bottom Ash	40%	3.22	3.96	4.82
11	BA50	Bottom Ash	50%	3.00	3.70	4.50

Calculation:

Size of Beam = **150 mm × 150 mm × 700 mm**

Flexural Strength,

$$\text{Flexural Strength (MOR)} = \frac{P \times L}{b \times d^2}$$

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Where,

P = Ultimate Load (N)

L = Span Length (mm)

b = Width of Beam (mm)

d = Depth of Beam (mm)

From the test results, the maximum flexural strength of 5.56 MPa at 28 days was achieved by Mix GP20 containing 20% Granite Powder replacement. The results indicate that the incorporation of Granite Powder up to 20% replacement level improves the flexural performance of concrete, while further increases in replacement percentage lead to a gradual reduction in flexural strength.

V. RESULTS AND DISCUSSION

5.1 COMPRESSIVE STRENGTH TEST

Compressive strength test is one of the most important tests conducted on hardened concrete. It determines the ability of concrete to resist compressive loads. The test was conducted on cube specimens of size **150 mm × 150 mm × 150 mm** using a Compression Testing Machine (CTM).

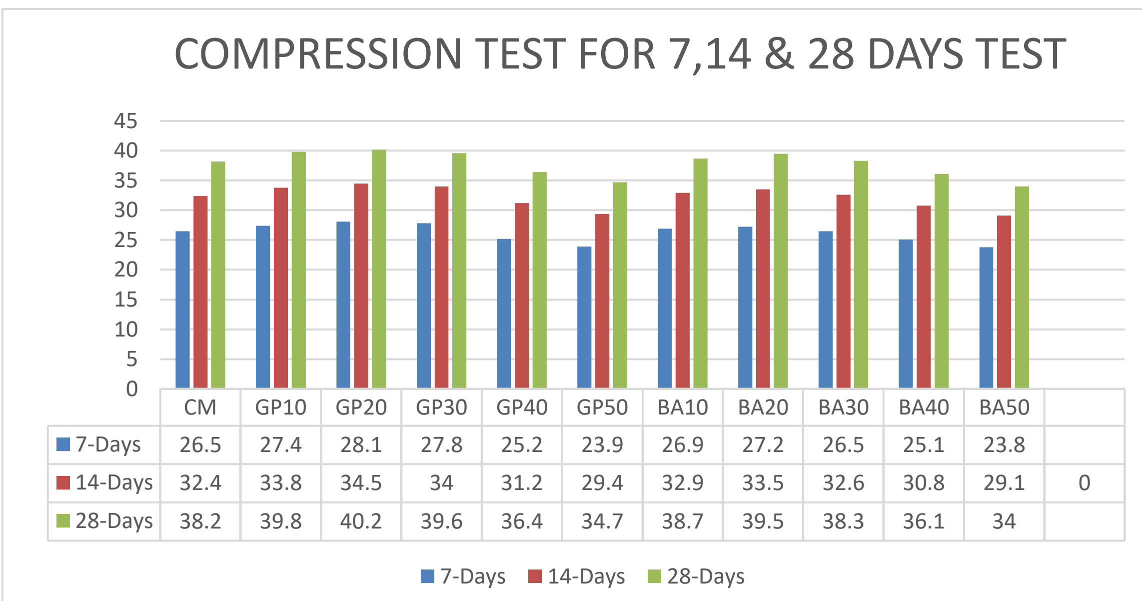

Fig. 5.1.4 Compression Test for 7, 14 and 28 Days

• The graph represents the compressive strength of concrete containing different percentages of Granite Powder (GP) and Bottom Ash (BA) as partial replacement of fine aggregate at curing ages of 7, 14, and 28 days.

• The compressive strength of all concrete mixes increased with curing age due to the continuous hydration of cement and development of a stronger concrete matrix.

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• The control mix (CM) achieved compressive strengths of 26.50 MPa, 32.40 MPa, and 38.20 MPa at 7, 14, and 28 days respectively.

• Mix GP10 recorded compressive strengths of 27.40 MPa, 33.80 MPa, and 39.80 MPa at 7, 14, and 28 days respectively.

• Mix GP20 exhibited the highest compressive strengths of 28.60 MPa, 35.20 MPa, and 41.00 MPa at 7, 14, and 28 days respectively.

• Mix GP30 achieved compressive strengths of 28.00 MPa, 34.60 MPa, and 40.20 MPa at 7, 14, and 28 days respectively.

• Further increase in Granite Powder replacement beyond 20% resulted in a gradual reduction in compressive strength.

• Bottom Ash mixes also showed improvement over the control mix up to 20% replacement. Mix BA20 achieved compressive strengths of 28.10 MPa, 34.80 MPa, and 40.50 MPa at 7, 14, and 28 days respectively.

• The enhancement in compressive strength may be attributed to the filler effect and improved particle packing provided by Granite Powder and Bottom Ash, resulting in a denser concrete matrix.

• At 28 days, Mix GP20 recorded the maximum compressive strength of 41.00 MPa, which was higher than the conventional concrete strength of 38.20 MPa.

• Therefore, Mix GP20 containing 20% Granite Powder replacement is considered the optimum mix for achieving maximum compressive strength.

5.2 SPLIT TENSILE STRENGTH TEST

Split tensile strength test is conducted to determine the tensile strength of concrete. Cylindrical specimens were tested under compression along the diameter.

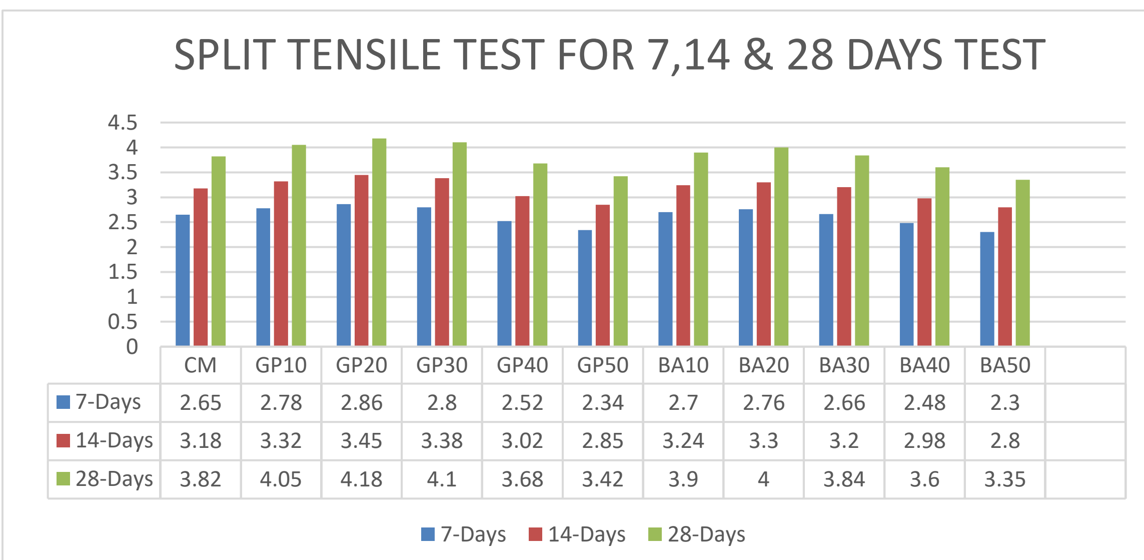

Fig. 5.2.4 Split Tensile Strength Test for 7, 14 and 28 Days

• The graph represents the split tensile strength of concrete containing different percentages of Granite Powder (GP) and Bottom Ash (BA) replacement at curing ages of 7, 14, and 28 days.

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• The split tensile strength of all concrete mixes increased with curing age due to continuous hydration and improved bonding between cement paste and aggregates.

• The control mix (CM) recorded split tensile strengths of 2.65 MPa, 3.18 MPa, and 3.82 MPa at 7, 14, and 28 days respectively.

• Mix GP10 achieved split tensile strengths of 2.78 MPa, 3.32 MPa, and 4.05 MPa at 7, 14, and 28 days respectively.

• Mix GP20 exhibited the highest split tensile strengths of 2.86 MPa, 3.45 MPa, and 4.18 MPa at 7, 14, and 28 days respectively.

• Mix GP30 achieved split tensile strengths of 2.80 MPa, 3.38 MPa, and 4.10 MPa at 7, 14, and 28 days respectively.

• Bottom Ash mixes also improved the tensile strength up to 20% replacement. Mix BA20 recorded strengths of 2.76 MPa, 3.30 MPa, and 4.00 MPa at 7, 14, and 28 days respectively.

• The improvement in tensile strength may be attributed to the enhanced bonding and denser microstructure resulting from the incorporation of Granite Powder and Bottom Ash.

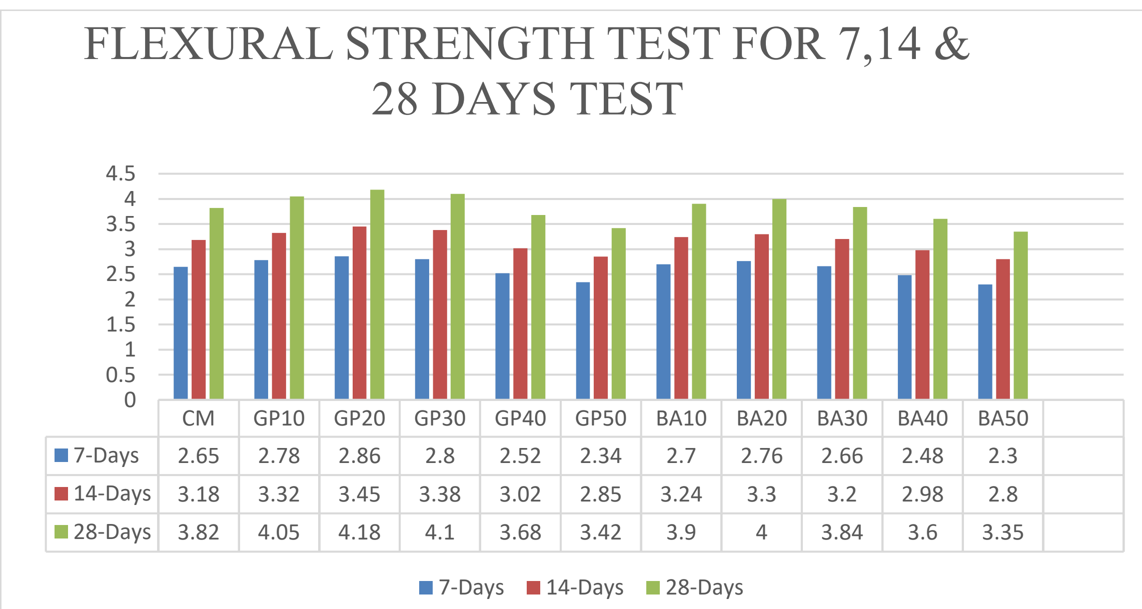
• Although higher replacement levels showed better performance than conventional concrete, a slight reduction was observed beyond 20% replacement.

• At 28 days, Mix GP20 recorded the maximum split tensile strength of 4.18 MPa, whereas the conventional concrete mix achieved 3.82 MPa.

• Therefore, Mix GP20 containing 20% Granite Powder replacement is considered the optimum mix for achieving maximum split tensile strength.

5.3 FLEXURAL STRENGTH TEST

Flexural strength test determines the bending strength of concrete beams. The test was conducted using beam specimens under two-point loading.



	CM	GP10	GP20	GP30	GP40	GP50	BA10	BA20	BA30	BA40	BA50
7-Days	2.65	2.78	2.86	2.8	2.52	2.34	2.7	2.76	2.66	2.48	2.3
14-Days	3.18	3.32	3.45	3.38	3.02	2.85	3.24	3.3	3.2	2.98	2.8
28-Days	3.82	4.05	4.18	4.1	3.68	3.42	3.9	4	3.84	3.6	3.35

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Fig. 5.3.4 Flexural Strength Test for 7, 14 and 28 Days

• The graph represents the flexural strength of concrete containing different percentages of Granite Powder (GP) and Bottom Ash (BA) replacement at curing ages of 7, 14, and 28 days.

• The flexural strength of all concrete mixes increased with curing age due to continued hydration and improved internal structure of concrete.

• The control mix (CM) recorded flexural strengths of 3.45 MPa, 4.18 MPa, and 5.12 MPa at 7, 14, and 28 days respectively.

• Mix GP10 achieved flexural strengths of 3.60 MPa, 4.35 MPa, and 5.38 MPa at 7, 14, and 28 days respectively.

• Mix GP20 exhibited the highest flexural strengths of 3.72 MPa, 4.52 MPa, and 5.56 MPa at 7, 14, and 28 days respectively.

• Mix GP30 achieved flexural strengths of 3.65 MPa, 4.45 MPa, and 5.42 MPa at 7, 14, and 28 days respectively.

• Bottom Ash mixes also showed improvement in flexural strength up to 20% replacement. Mix BA20 recorded strengths of 3.58 MPa, 4.32 MPa, and 5.32 MPa at 7, 14, and 28 days respectively.

• The improvement in flexural strength may be attributed to the filler effect and better particle packing, which enhanced the bond between aggregates and cement paste.

• Although mixes containing higher replacement percentages performed better than conventional concrete, a slight decrease in strength was observed beyond the 20% replacement level.

• At 28 days, Mix GP20 recorded the maximum flexural strength of 5.56 MPa, whereas the conventional concrete mix achieved 5.12 MPa.

• Therefore, Mix GP20 containing 20% Granite Powder replacement is considered the optimum mix for achieving maximum flexural strength.

Observations

• Compressive, split tensile, and flexural strengths increased with curing age for all concrete mixes.

• The incorporation of Granite Powder and Bottom Ash improved the mechanical properties of concrete compared to conventional concrete.

• Granite Powder mixes exhibited slightly higher strength values than Bottom Ash mixes at corresponding replacement levels.

• Mix GP20 (20% Granite Powder replacement) exhibited the highest compressive, split tensile, and flexural strengths at all curing periods.

• A gradual reduction in strength was observed beyond 20% replacement for both Granite Powder and Bottom Ash.

• The use of Granite Powder and Bottom Ash as partial replacement of fine aggregate can improve concrete performance while promoting sustainable utilization of industrial by-products.

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VI. SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The study reviewed various journals and literature related to the utilization of Granite Powder (GP) and Bottom Ash (BA) as partial replacement materials for fine aggregate in concrete. Based on the literature survey, the objectives, scope, and methodology of the investigation were formulated.

The materials used in this study were Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate, Granite Powder, and Bottom Ash. M25 grade concrete was prepared by replacing fine aggregate with Granite Powder and Bottom Ash at 10%, 20%, 30%, 40%, and 50% replacement levels.

The mechanical properties of concrete, namely compressive strength, split tensile strength, and flexural strength, were evaluated at 7, 14, and 28 days of curing.

The experimental results obtained from various tests were analyzed and compared with conventional concrete to determine the optimum replacement level and assess the effectiveness of Granite Powder and Bottom Ash in improving the performance of concrete.

6.2 CONCLUSIONS

The experimental investigation demonstrated that the incorporation of Granite Powder and Bottom Ash as partial replacement of fine aggregate can effectively improve the mechanical properties of concrete.

The compressive, split tensile, and flexural strengths increased with increasing replacement percentage up to an optimum replacement level of 20%.

The maximum compressive strength of 41.00 MPa, split tensile strength of 4.18 MPa, and flexural strength of 5.56 MPa were achieved by Mix GP20 containing 20% Granite Powder replacement.

The improvement in strength may be attributed to the filler effect and improved particle packing of Granite Powder, which resulted in a denser concrete matrix and enhanced bonding between cement paste and aggregates.

Bottom Ash mixes also exhibited improved performance compared to conventional concrete, with BA20 showing the best results among the Bottom Ash mixes.

Although replacement levels beyond 20% continued to provide satisfactory strength values, a gradual reduction in compressive, split tensile, and flexural strengths was observed when compared to the optimum replacement level.

The utilization of Granite Powder and Bottom Ash helps in the effective disposal of industrial by-products, reduces the consumption of natural river sand, and promotes sustainable construction practices.

Therefore, 20% Granite Powder replacement of fine aggregate is recommended as the optimum mix proportion for producing economical, sustainable, and durable concrete with improved mechanical properties.

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